STATUS OF CCS/DOE R&D PROGRAM

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Global CCS Institute
NAS Workshop on Direct Air Capture
October 24, 2017

Aerial view of Tomakomai CCS Demonstration Project facilities located at Tomakomai City, Hokkaido, Japan. Image provided by JCCS.
One mission: to accelerate CCS deployment on a global scale by increasing . . .

- **Public understanding** and acceptance of Carbon Capture
- **Policy support** for Carbon Capture, and
- **Commercial opportunities** for Carbon Capture
Actual and expected operation dates up to 2022 for large-scale CCS facilities by industry and storage type

Assessing CCS possibilities from ammonia production, from cement production and from waste-to-energy sources

* Facilities in the Operating, In construction and Advanced development stages

= 1Mtpa of CO₂ (area of circles proportional to capacity)
Cost/Complexity Increase at Lower CO$_2$ Concentrations

Cost/Complexity of Removing CO$_2$ from Selected Sources
DOE Fossil Energy Program

**Major Demonstrations**
First Generation fossil energy technology systems built to validate first-of-a-kind fully integrated projects at full scale for the power and industrial sectors.

**Advanced Energy Systems**
Technologies that greatly improve plant efficiencies, reduce CO₂ capture costs, increase plant availability, and maintain the highest environmental standards.

**Carbon Capture**
R&D and scale-up technologies for capturing CO₂ from new and existing industrial and power-producing plants.

**Carbon Storage**
Safe, cost-effective, and permanent geologic storage of CO₂ in depleted oil and gas fields and other formations.

**Cross Cutting Research**
Materials, sensors, and advanced computer systems for future power plants and energy systems.
Pathway for technology commercialization

Probability of successful outcome relies on large number of potential options!

Large number of potential options

Laboratory/Bench-Scale

Small Pilot-Scale

Large Pilot-Scale

Demonstration

Commercial

Limited number of successful outcomes

= Technology Options

Transfer to Office of Major Demonstrations

Scope of Capture Program

TRL 2 Successes from FWP, SBIR/STTR, ARPA-E
Cost reduction targets

<table>
<thead>
<tr>
<th>Technology Type</th>
<th>COE Relative to Today’s Coal with Capture (%)</th>
<th>Year</th>
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<tbody>
<tr>
<td>IGCC or Supercritical PC</td>
<td>0% Reduction</td>
<td>State-of-the-Art</td>
</tr>
<tr>
<td>2nd Generation Technology</td>
<td>20% Reduction</td>
<td>2025 Demo</td>
</tr>
<tr>
<td>Transformational Technology</td>
<td>30% Reduction</td>
<td>2030 Demo</td>
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</table>
R&D areas

Pre-Combustion
- Solvents
- Sorbents
- Membranes
- Hybrid processes
- Water-gas shift reactor

Advanced Combustion
- Atmospheric oxy-combustion
- Pressurized oxy-combustion
- Oxygen transport membrane
- Chemical looping

Advanced Compression
- Intra-stage cooling
- Cryogenic pumping
- Supersonic shock wave compression

Advanced Combustion
- Chemical looping

Advanced Compression
- Supersonic shock wave compression

Post-Combustion
- Solvents
- Sorbents
- Membranes
- Hybrid processes

Advanced CO₂ Capture Technology Development
- Process Chemistry
- Chemical Production Method
- Process Equipment Design
- Equipment Manufacturing Method
- Process Integration
# Post-Combustion Carbon Capture

## Barriers

**Cost:** Economically generating clean energy using fossil fuels; **Performance:** Achieve performance targets by 2030; **Environment:** Meet near-zero emissions (including >90% CO₂ capture) with minimal cost impact; **Market:** Low economic growth; lower natural gas price; **Regulations:** Uncertainties

<table>
<thead>
<tr>
<th>Key Technology</th>
<th>Challenges</th>
<th>Research Focus</th>
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<tbody>
<tr>
<td><strong>Solvents</strong></td>
<td>▪ Tradeoff between heat of reaction and kinetics</td>
<td>✓ Advanced Solvents</td>
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<tr>
<td></td>
<td>▪ Significant amounts of steam to reverse chemical reactions and regenerate the solvent</td>
<td>✓ Process Intensification</td>
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<tr>
<td></td>
<td>▪ Energy required to heat, cool, and pump non-reactive carrier liquid (usually water) is often significant</td>
<td>✓ Functionalized/Catalyzed/Phase Change</td>
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<td></td>
<td>▪ Vacuum stripping can reduce regeneration steam requirements, but increases compression loads</td>
<td>✓ Hybrid Systems</td>
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<tr>
<td></td>
<td></td>
<td>✓ Kinetic Improvements</td>
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<tr>
<td><strong>Sorbents</strong></td>
<td>▪ Moderate heat required to reverse chemical reaction</td>
<td></td>
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<tr>
<td></td>
<td>▪ Heat management in solid systems is difficult</td>
<td></td>
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<tr>
<td></td>
<td>▪ Pressure drop can be large in flue gas applications</td>
<td>✓ Process Enhancement/ Rapid TSA-PSA</td>
</tr>
<tr>
<td></td>
<td>▪ Sorbent attrition</td>
<td>✓ Materials/Structured Adsorbents</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ Hybrid Systems</td>
</tr>
<tr>
<td><strong>Membranes</strong></td>
<td>▪ Membranes tend to be more suitable for high-pressure processes such as IGCC</td>
<td>✓ High-Density Membranes</td>
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<tr>
<td></td>
<td>▪ Tradeoff between recovery rate and product purity</td>
<td>✓ Novel Materials</td>
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<td></td>
<td>▪ Requires high selectivity</td>
<td>✓ Nano-Materials</td>
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<td></td>
<td>▪ Poor economy of scale</td>
<td>✓ Novel Process Conditions</td>
</tr>
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<td></td>
<td>▪ Multiple stages, recycle streams may be required</td>
<td>✓ Hybrid Systems</td>
</tr>
</tbody>
</table>

**Justification:** 90% CO₂ capture directly applicable to over 300GW of existing electric power generation; minimal revision of existing PC platform; can be easily extended to natural gas and industrial sources; leverages existing equipment/infrastructures.
## Compare/contrast CCS vs. DAC

<table>
<thead>
<tr>
<th>Issue/Factor</th>
<th>CCS</th>
<th>DAC</th>
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<tbody>
<tr>
<td><strong>Scale</strong></td>
<td>0.1 – 1+ Mt/yr</td>
<td>Hundreds – Thousands t/yr</td>
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<td></td>
<td>• Petra Nova 1.4 Mt/yr</td>
<td>• Climeworks 900 t/yr</td>
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<td></td>
<td>• BD 0.8 – 1 Mt/yr</td>
<td>• Carbon Engineering 1 t/day</td>
</tr>
<tr>
<td></td>
<td>• 17 LSIPs &gt;0.4 Mt/yr</td>
<td>• Smaller scale possible – distributed removal</td>
</tr>
<tr>
<td></td>
<td>• Multiple smaller scale 0.1 – 0.4 Mt/yr</td>
<td>• ???</td>
</tr>
<tr>
<td></td>
<td>• 2(^{nd}) Generation pilots 10 – 500 t/day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Has to be large scale</td>
<td></td>
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<tr>
<td><strong>Limitations</strong></td>
<td><strong>Technical</strong></td>
<td><strong>Technical</strong></td>
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<tr>
<td></td>
<td>• Thermodynamic minimum for amines</td>
<td>• Driving force</td>
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<tr>
<td></td>
<td>• Scale-up of 2(^{nd}) Generation and Transformational</td>
<td>• Source of regeneration energy</td>
</tr>
<tr>
<td></td>
<td><strong>Social</strong></td>
<td>• ???</td>
</tr>
<tr>
<td></td>
<td>• Policy parity</td>
<td><strong>Social</strong></td>
</tr>
<tr>
<td></td>
<td>• Incentives</td>
<td>• Not on radar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Enhanced incentives (?)</td>
</tr>
</tbody>
</table>
## Compare/contrast CCS vs. DAC

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</table>
| **Cost**           | • Huge capital requirements  
                    • High-cost financing  
                    • Perception as experimental  
                    • Minimize financial and technical risk | • Lower cost/installation  
                    • Drive down $/tonne (rate?)  
                    • Utilization opportunities  
                    • Local economic development  
                    • Sub-national governments |
| **Research Program** | • Reduced CAPEX and OPEX  
                    • Scale-up  
                    • Wandering targets  
                    — 2010: <30% COE+  
                    — 2011: <35% COE+  
                    — 2012: $40/tonne by 2025  
                    — 2013: $40/tonne by 2030  
                    — 2014: decrease COE by 20% vs current tech  
                    • Funding for commercialization valley of death | • Reduced costs  
                    • Materials, processes, equipment  
                    • Modular  
                    • Market analysis/definition  
                    • Resilient targets/metrics  
                    • Well-defined plan for outreach/education of stakeholders and policy-makers  
                    • Engagement between researchers and advocacy groups (eg NGOs) |
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